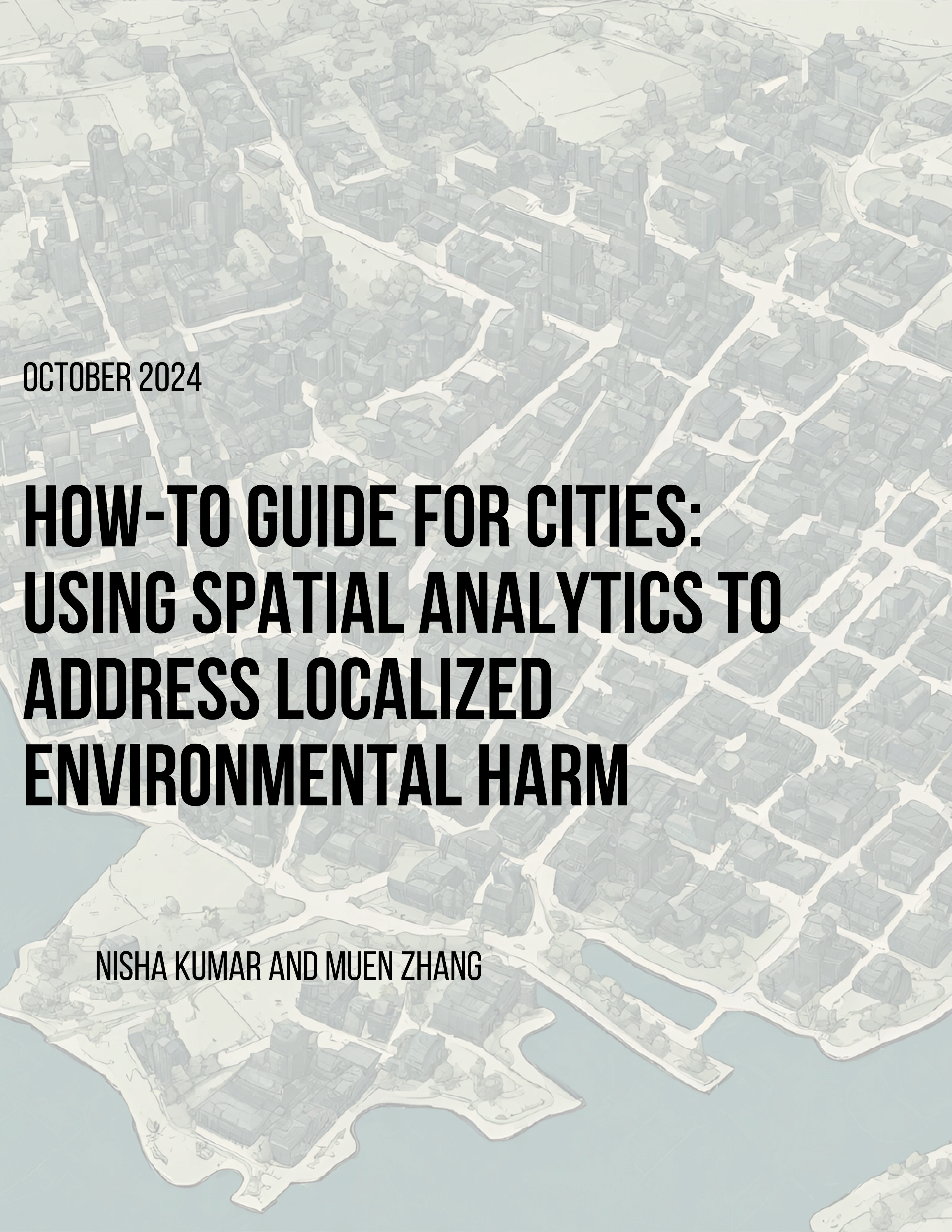
OCTOBER 2024

HOW-TO GUIDE FOR CITIES: USING SPATIAL ANALYTICS TO ADDRESS LOCALIZED ENVIRONMENTAL HARM

NISHA KUMAR AND MUEN ZHANG



OCTOBER 2024

HOW-TO GUIDE FOR CITIES: USING SPATIAL ANALYTICS TO ADDRESS LOCALIZED ENVIRONMENTAL HARM

NISHA KUMAR AND MUEN ZHANG

About Data-Smart City Solutions

Data-Smart City Solutions at the Bloomberg Center for Cities at Harvard University is working to catalyze the adoption of data projects on the local government level by serving as a central resource for city leaders. We highlight best practices, top innovators, and promising case studies while also connecting leading industry, academic, and government officials. Our research focuses on the intersection of government and data and explores innovations in open data, predictive analytics, and civic engagement technology. We seek to discover and preemptively address civic problems by integrating cross-agency data with community data.

About the Community Data Health Initiative

The Community Data Health Initiative is a collaboration among the Data-Smart City Solutions program at the Bloomberg Center for Cities at Harvard University, the Environmental Defense Fund, and the African American Mayors Association. Launched in 2022, the initiative assists mayors and city leaders in utilizing data to address localized environmental issues, with a key focus on improving health outcomes for communities disproportionately affected by environmental hazards like air pollution and extreme heat.

With generous funding from the Robert Wood Johnson Foundation and the Kresge Foundation, this initiative works closely with a group of partner cities on pilot projects, with the goal of sharing learnings and best practices across city networks nationwide.

About the Authors

Nisha Kumar, MPP is the Program Manager for the Community Data Health Initiative (CDHI), leading CDHI for the Data-Smart City Solutions team at The Bloomberg Center for Cities at Harvard University. With partners at the Environmental Defense Fund and African American Mayors Association, she supports city leaders in using municipal levers to address health disparities brought on by environmental pollutants. Kumar currently oversees projects on air pollution and extreme heat in Baltimore, the District of Columbia (DC), and Baton Rouge.

She brings expertise in public health and has worked on Medicare policy at the federal level, Medicaid behavioral health policy with the state of California, and now local public health initiatives with CDHI. Kumar holds a master's degree in public policy from the Harvard Kennedy School and a bachelor's degree in public health from the University of California, Berkeley.

Muen Zhang is a third-year Master in Landscape Architecture student at the Harvard Graduate School of Design, with a strong focus on leveraging data analytics and information technologies to address complex urban and environmental challenges. Prior to pursuing her current studies, Zhang gained diverse experience across architecture, NGOs, and impact investing. She holds a Bachelor of Science in Architecture from the Karlsruhe Institute of Technology, where she specialized in building technology.

Acknowledgements

This paper was developed and written with the invaluable assistance and contributions of Erica Ivins, who was the Project Coordinator for the Community Data Health Initiative and integral part of this team.

This paper was reviewed by subject matter experts Ananya Roy from the Environmental Defense Fund and Khahlil Louisy from the Institute for Technology and Global Health and the World Health Organization.

It was produced with the support of the Robert Wood Johnson Foundation and the Kresge Foundation. The authors are grateful for the foundations' investment in our work.

DATA-SMART CITY SOLUTIONS

A PUBLICATION OF

Data-Smart City Solutions
79 John F. Kennedy Street Cambridge, MA 02138
datasmart.hks.harvard.edu

BLOOMBERG CENTER FOR CITIES
HARVARD UNIVERSITY

Introduction

Where you live profoundly impacts your health. Across U.S. cities, environmental hazards like air pollution and extreme heat disproportionately affect low-income neighborhoods and communities of color, shaped by historical disinvestment and discriminatory policies like redlining. Yet, neighborhood-level disparities often go unaddressed because environmental regulations typically focus on national or county scales, while local transportation and land use decisions have historically overlooked environmental and health impacts, partly due to the lack of localized data that is now available.

The Community Data Health Initiative (CDHI) launched in 2022 to help cities bridge that gap by using neighborhood scale data to address hyperlocal environmental harms and improve health in the most vulnerable communities. Given the central role of place in this work, geographic information system (GIS) is a vital tool, enabling cities to layer spatial data to track burden and health disparities to identify where interventions are most needed.

Last year, CDHI brought together the four pilot cities it supports—Washington, D.C., Baltimore, Baton Rouge, and Detroit—alongside experts from the GIS software company Esri to discuss how spatial data could inform the cities' air pollution and heat mitigation efforts. What emerged from those discussions was that, too often, GIS was being used as a reference tool only at the initial problem assessment stage, rather than being embedded throughout the decision-making process. Most of the hurdles weren't about a lack of spatial data or GIS tools, but rather about uncertainty over where to start, which data to prioritize and how to navigate challenges in data accessibility, and how to establish functional cross-agency systems with analytic capacity to carry out the work. Additionally, health data was often excluded from decision-making, even though improving health is a key goal of many environmental initiatives. To address this, CDHI designed a practical framework to help city teams working on environmental issues embed GIS into the policymaking process with a focus on equity and health, informed by conversations with its city partners, Esri, and academic institutions.

Section I highlights the value and potential for expanding the use of GIS, featuring success stories from various cities. Section II provides a step-by-step framework for implementing that expansion. Sections III and IV then apply the framework to two key focus areas of CDHI—air pollution and urban heat mitigation—assuming familiarity with these policy areas. While the examples center on air and heat, the framework is also adaptable to other environmental exposures, such as lead exposure or water contamination.

I. The Case for Spatial Analytics: Success Stories from Cities

GIS is more than a technical tool—it offers a practical way to embed data into decisions, ensuring that they integrate equity and health lenses. There are three areas where the role of GIS is particularly important in this context. The first is messaging up to mayors and aligning city staff. GIS offers city leadership clear, data-backed insights into pressing environmental issues, making it easier to prioritize investments and coordinate across departments. By visually mapping factors under a mayor's control, such as infrastructure or transportation activity, alongside exposures, burdens and vulnerable populations, GIS fosters cohesive decision-making. The second is messaging out to communities and incorporating their input. Maps can simplify communication of complex environmental challenges, helping residents understand the impact of pollution or heat in their neighborhoods relative to the rest of the city and potential contributors to any differences. The third is informing policy design and implementation. GIS can support the entire policy lifecycle, from problem identification to ongoing evaluation and adaptation. Many cities are already incorporating GIS into the following stages of the policymaking process:

- **Prioritizing Investments and Interventions:** GIS empowers cities to apply spatial data in both big-picture strategic thinking and day-to-day decision making. Cities can use the data to craft climate action plans with precise goals for pollution reduction in specific neighborhoods. For instance, Los Angeles combined building energy use, transportation data, and green space metrics to establish data-driven goals for reducing emissions in areas most impacted by pollution.[i] On a more operational level, GIS helps cities pinpoint areas in need of immediate action; for example, Hopkins, Minnesota used its Heat Vulnerability Map to identify a specific hot corridor linked to the METRO Green Line Extension that is now the target site for interventions.[ii]
- **Incorporating Community Voice:** GIS can also be used to integrate community data to ensure alignment with lived experiences and ensure that public input shapes response. For example, Multnomah County, Oregon used GIS to integrate citizen scientist data into its Heat Vulnerability Index and risk assessment tool.[iii] Over 100 resident volunteers gathered temperature data using mobile sensors along 41 routes, which was then combined with building, air conditioning, and tree canopy data to identify at-risk areas.[iv]
- **Tracing and Regulating Pollution Sources:** GIS enables cities to identify proximal pollution sources, such as traffic corridors or industrial sites, informing targeted regulations like traffic rerouting or stricter emissions standards, reducing pollution at the source. In New York City, GIS data exposed the disproportionate impact of pollution from truck-attracting facilities on nearby residents.[v] The city then enacted an indirect source rule to regulate warehouse emissions in affected neighborhoods.[vi]
- **Securing Funding:** Spatial data provides the hard evidence cities need to secure funding. Since 2022, the Inflation Reduction Act has opened new grant opportunities that support local, place-based equity initiatives. CDHI has assisted cities in applying for the Environmental Protection Agency's Climate Pollution Reduction Grants[vii] and Air Quality Information[viii] funding–both of which required spatial data to demonstrate need.
- **Monitoring and Evaluating Impact:** GIS enables cities to monitor interventions and adjust strategies as new data emerges. For example, ResillientMass mapped environmental justice areas in Massachusetts–specifically low-income, non-English

speaking, and racial-ethnic minority communities–against the density of construction projects and tailored their evaluation process to develop hazard mitigation plans.[ix]

II. A Strategic Framework for Leveraging Spatial Data to Improve Environmental Health

This section introduces CDHI's framework, which provides four steps to strategically organize spatial data to achieve the goals outlined in Section I, with a specific focus on embedding equity and health considerations into your teams' environmental work.

First, for this process to succeed, it is important to have the right people at the table early. This includes internal staff with relevant policy expertise, data familiarity, and decision-making authority as well as cross-departmental teams that touch the issue, like environmental or sustainability, public health, and GIS. Depending on capacity and buy-in across teams, this engagement may happen upfront, or mapping can serve as a tool to engage others later through an iterative process. Regardless, involving diverse perspectives early can help ensure alignment on the approach and answer the questions presented in the framework's steps below.

Step 1: Map Exposure
The first step involves defining environmental exposure based on your city's local conditions and priorities and then visualizing their distribution. Key questions to guide this process include:

- What types of exposure are most relevant, and what should be mapped?
- How high is that exposure across the city?
- Where are the hotspots?
- Where are the major sources of emissions?

Step 2: Map Outcomes
This step shifts focus to the impact on people, primarily looking at health outcomes but potentially also including other factors like education, employment, or well-being as relevant. Evaluating these outcomes is crucial, as they can reveal vulnerabilities and highlight different hotspots than pollution data alone. Key questions to guide this process include:

- What are the key health burdens associated with the exposure(s) of interest?
- How are these burdens distributed, and where are the hotspots?
- Are there areas where high health burdens and environmental exposures overlap? Alternatively, do new hotspots emerge when health data is incorporated?

Step 3: Map Community Conditions
The third step evaluates the many social and demographic factors that shape vulnerability and amplify environmental risks, such as race, age, income, and access to resources. Key questions to guide this process include:

- What groups are most vulnerable to the outcome(s) of interest?
- Where are those groups located?
- Who lives in the neighborhoods with high environmental exposures and health burdens?
- What social determinants and factors heighten their vulnerability?

Step 4: Place Interventions
The fourth step translates data insights into action. At this stage, teams may either have specific interventions in mind or be using the data to explore potential solutions. For teams with defined plans, the focus is on prioritizing where to implement them based on the data. For those still exploring options, data on exposures, outcomes, and community conditions can help identify gaps and guide decisions on the most impactful interventions. Key questions to guide this process include:

- Where is the greatest harm, and where can the city make the most impact?
- If interventions are already planned, where should they be prioritized?
- If no interventions are decided, what does the data suggest about possible solutions?
- What existing programs are in place, and where are there gaps or opportunities?

III. Applying the Framework: Air Pollution

This section applies the framework from Section II to the challenge of addressing air pollution at the city level. Each step includes common practices and considerations for selecting data layers, followed by a case study showing how CDHI used the framework to create an ArcGIS Storymap[x] for D.C. to inform where to place new air quality sensors to better capture disparities in neighborhoods experiencing greater burden and vulnerability.

Step 1. Map Exposure

To effectively address air pollution through an equity lens, it is important to first define "exposure" in a way that reflects your local context. Doing so requires moving beyond the traditional approach of assessing overall pollution – which often considers all criteria[xi] or hazardous pollutants[xii] categorized by the EPA – to account for factors like local industrial and transportation activity, community-specific health vulnerabilities, and historical harm in certain neighborhoods. There are three important lenses to consider when selecting the pollutants relevant to your city's context and your mayor's priorities:

1. **Priority Sources**: This lens prioritizes pollutants emitted from specific sources such as highways, industrial facilities, and power plants. It is important to consider your city's major industry and emitters when deciding which pollutants are relevant. The EPA's National Emissions Inventory (NEI) offers detailed data on major point sources and polluting industries, while Department of Transportation (DOT) traffic monitors and local transportation departments can provide data on vehicle activity and emissions.
2. **Health Impacts**: This lens prioritizes pollutants strongly linked to poor health outcomes. One approach is to select pollutants with the widest array of health impacts to get a sense of overall burden. A second approach is to select a pollutant with ties to a specific outcome of interest. For example, if your mayor has stated priorities around maternal health, you may select $PM_{2.5}$ given its ties to birth outcomes.
3. **Contribution to Disparities**: This lens prioritizes pollutants with a high potential to contribute to disparities based on their spread. This is an essential component of any equity-focused effort, but still must be weighed alongside the other two lenses because certain pollutants that rank higher on disparities may not be as relevant to your city based on the industry spread and potential sources.

The following table outlines how to select pollutants using these three lenses, with the health impacts of concern focusing on those that can be linked to easily accessible health data.[xiii]

Selecting Pollutants: 3 Lenses					
Priority sources	**Ozone**	**PM 2.5**	**NO2**	**BC**	**VOCs**
Port	✓	✓	✓	✓	✓
Light-duty Vehicles	✓	✓	✓		✓
Medium- and Heavy-Duty Vehicles	✓	✓	✓	✓	✓
Industry (depending on type)	✓	✓	✓		✓
Residential or commercial energy	✓	✓	✓		
Power plants	✓	✓	✓		
Waste incineration	✓	✓	✓		✓
Health impacts	**Ozone**	**PM 2.5**	**NO2**	**BC**	**VOCs**
Mortality	✓	✓	✓	✓	
Heart Disease		✓			
Cancer		✓		✓	✓
Childhood asthma	✓	✓	✓		✓
Adverse birth outcomes		✓			
Emergency room visits respiratory disease	✓	✓	✓		
Hospitalizations for heart disease		✓			
Potential contribution to exposure disparity	Low	Medium	High	High	Highest

Cities can then use a combination of monitoring data, satellite data, and modeled data to capture real-time and estimated levels of the selected pollutants. Ideally, localized monitoring data serves as the primary input. The EPA's Air Quality System (AQS)[xiv] provides real-time and historical data collected from federal, state, and local air monitoring stations. AirToxScreen then adds finer detail by estimating hazardous air pollutant concentrations at the census block level. In areas with sparse ground-level monitors, satellite-derived data offers a broader perspective. NASA's Health and Air Quality Applied Sciences Team (HAQAST)[xv] provides high-resolution satellite data that covers a wide range of pollutants and can help cities screen pollution hotspots and patterns over large areas.

Seeing it in Action: Mapping $PM_{2.5}$ Exposure in Washington, D.C.

We focused on $PM_{2.5}$ in D.C. due to its known role in exacerbating childhood asthma, a policy priority for the mayor, and its significance as a traffic-related air pollutant. Transportation emissions vary widely across the city with truck emissions differing by over 400% between census tracts, and communities of color facing the highest exposure.[xvi] Using data developed by scientists at University of Vermont and the Environmental Defense Fund (EDF), we mapped road segment traffic emission rates in grams per mile per day.

Figure 1 reveals numerous high emission roads that run through the city, with two areas standing out: the city center where multiple such roads converge and the southeastern area where two major roads, Interstates 695 and 295, intersect.

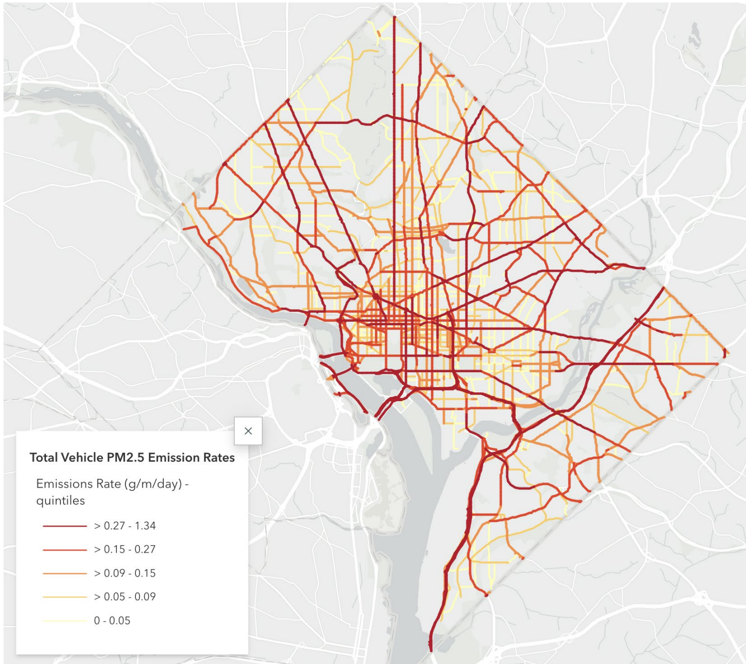


Figure 1. $PM_{2.5}$ Daily Roadway Emission Rates

Step 2. Map Outcomes

Air pollution is linked to a range of serious health effects, including respiratory conditions like asthma, cardiovascular diseases, and premature mortality. Long-term exposure to pollutants can also exacerbate chronic diseases and contribute to heart attacks, strokes, and lung cancer.

Localized data from health departments and health systems is critical for tracking these health impacts across neighborhoods, with cities typically relying on hospital admissions, emergency room (ER) visits, and mortality rates as key indicators. That said, city departments often have difficulty accessing this data from local or state health departments due to privacy concerns. The effort is still worthwhile as it has worked in numerous cities -- with particular success with asthma data -- and offers irreplaceable accuracy and precision, but there is often a practical need for interim options.

One common workaround is to start with CDC PLACES, which provides modeled health data on conditions like asthma, heart disease, and diabetes at the local level.[xvii] This modeled data can then be paired with state- and county-level data from resources like CDC WONDER (for mortality) and HCUP SID and HCUP SEDD (for hospitalizations and ER visits) to get closer to understanding the broader health impacts of pollution when localized health data isn't available.

Air pollution also has numerous social and economic consequences beyond health impacts, including increased school absenteeism, reduced workplace productivity, and higher healthcare costs. Cities should therefore consider adding data layers for related indicators like absenteeism from local school districts. Some of these metrics, in a way, can serve as proxies for health outcome data like higher healthcare costs or absenteeism.

Seeing it in Action: Tracking Asthma Rates in Washington, D.C.
We first used CDC PLACES data to map asthma prevalence across D.C. and found that neighborhoods with the highest asthma rates generally also had the highest $PM_{2.5}$ emissions from vehicles. Figure 2 shows that the majority of census tracts with elevated asthma rates, approximately 76% of them, are concentrated at the southern tip of the city in Ward 8.

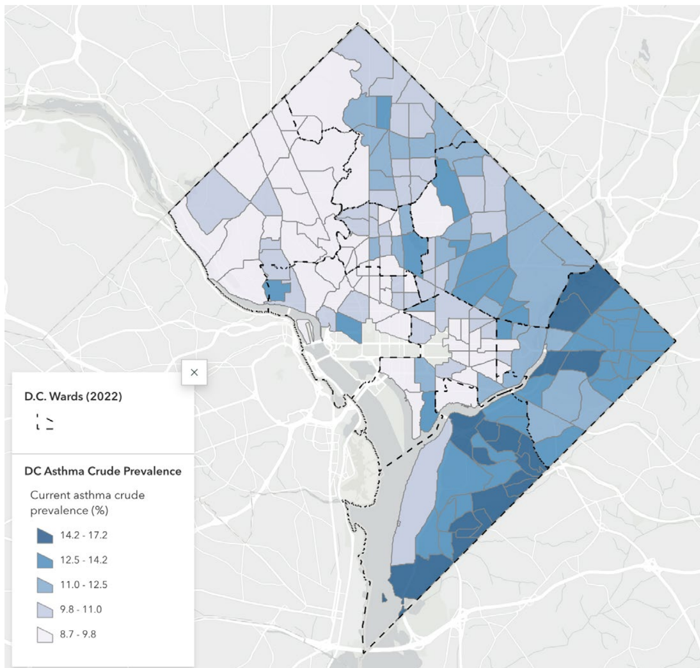


Figure 2. Asthma Crude Prevalence

We then explored $PM_{2.5}$-attributable mortality rates in individuals aged 65 and older, which we will discuss in Step 3, focusing on the intersection of this data with race.

Step 3. Map Community Conditions

Cities can leverage national and localized tools designed to assess vulnerability and guide interventions. National indices like the CDC/ATSDR Social Vulnerability Index (SVI)[xviii] and EPA's Environmental Justice Screening and Mapping Tool (EJScreen)[xix] offer broad insights into sociodemographic factors that affect vulnerability to air pollution. Meanwhile, localized tools, such as the equity indices developed by Esri in collaboration with cities like Los Angeles[xx] and Tacoma[xxi] provide more tailored data that reflects each city's specific needs.

Additionally, federal resources like the White House Climate and Economic Justice Screening Tool (CEJST) are invaluable for identifying communities eligible for support under the Justice40 Initiative.[xxii] This tool can be used to supplement city-level demographic data, providing a comprehensive understanding of local community conditions and helping guide investment decisions and apply for funding. The U.S. Climate Vulnerability Index (CVI), developed by EDF and Texas A&M University, is another key resource that visualizes neighborhood environmental health vulnerability and the conditions that shape it, including air pollution data, point source proximity, population density, and health status at the census tract level.[xxiii]

Cities typically consider several factors when mapping community conditions: identifying high-risk groups like children, the elderly, and those with pre-existing respiratory and cardiovascular conditions using data from the U.S. Census Bureau and the American Community Survey (ACS); pinpointing communities near pollution sources such as highways or industrial zones with help from SVI and zoning data; and highlighting historically marginalized, low-income communities—often Black and Brown—who face higher pollution levels due to historical redlining and zoning practices, using data from HUD and local housing authorities.

Seeing it in Action: Identifying Sensitive Groups in Washington, D.C.

We began by looking at two factors—low-income and people of color[xxiv] population percentages—since research shows that $PM_{2.5}$ disproportionately affects these groups, particularly in Wards 7 and 8.[xxv, xxvi, xxvii] EJScreen data revealed these wards have high concentrations of low-income residents, elevated asthma rates, and $PM_{2.5}$ emissions, with an even stronger overlap in areas with high percentages of people of color. The data also highlighted similar overlap in Wards 4 and 5 in the north and northeast.

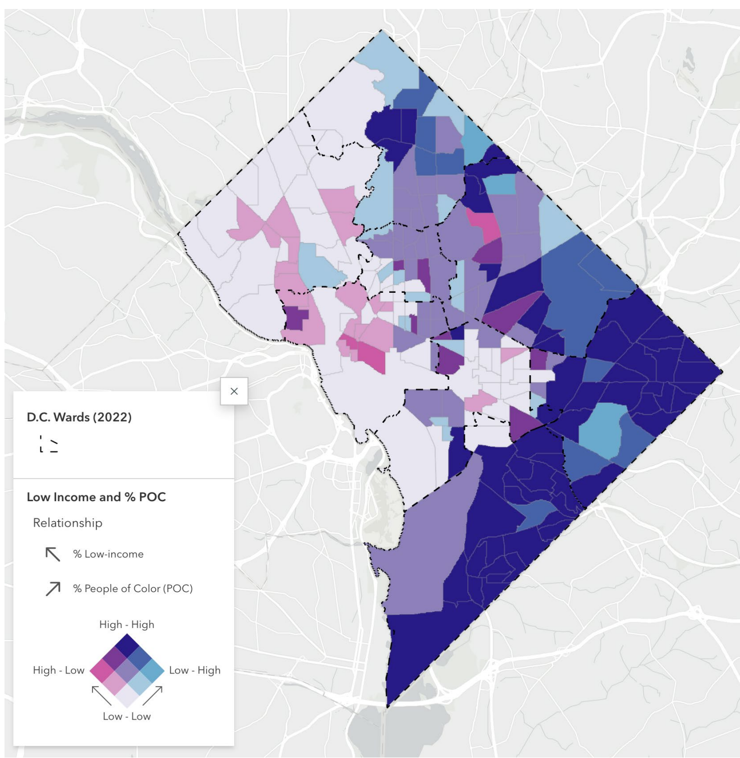


Figure 3. Percentage of Low-income Population and People of Color

Next, we looked at $PM_{2.5}$ attributable mortality rates by race and found a stark contrast, as shown in Figure 4, with rates roughly four times higher for Black populations (see right) compared to White populations (see left) across the city.

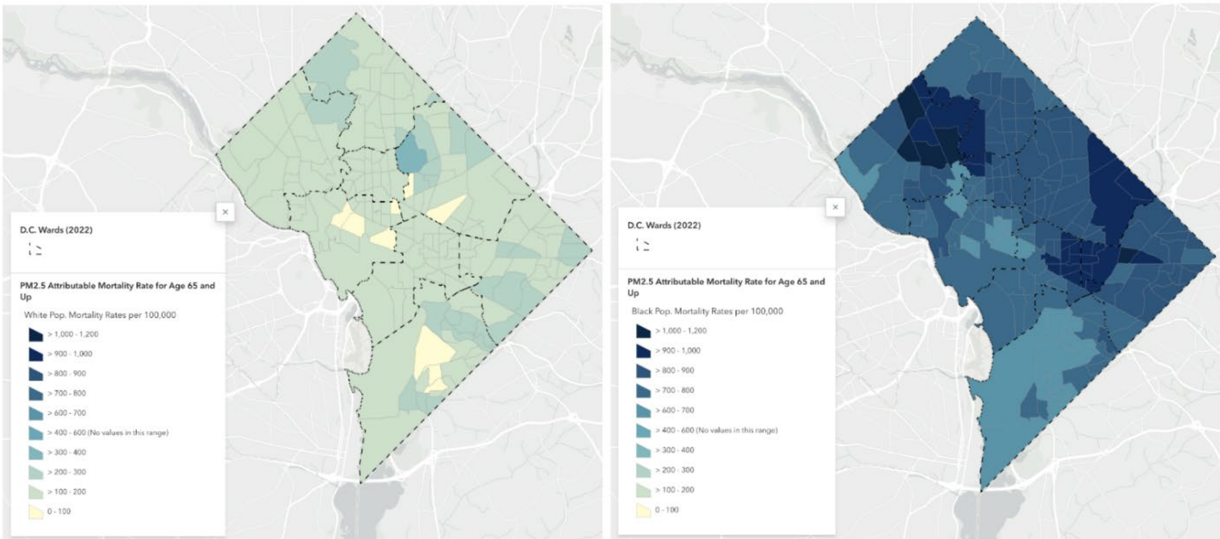


Figure 4. $PM_{2.5}$ Attributable Mortality Among White (left) vs. Black Populations (right)

Finally, we analyzed a particularly sensitive group, school children, whose developing respiratory systems are especially sensitive to air pollution.[xxviii] We focused on Title 1 schools, which serve low-income families and represent a high-risk population. By mapping these schools and applying a 500-meter buffer around major roads in Figure 5, we identified several Title 1 schools near high-emission road segments, particularly in the southern and southeastern parts of the city.[xxix] Many of these schools are also located in neighborhoods with higher rates of ER visits for asthma among children aged 0-18.

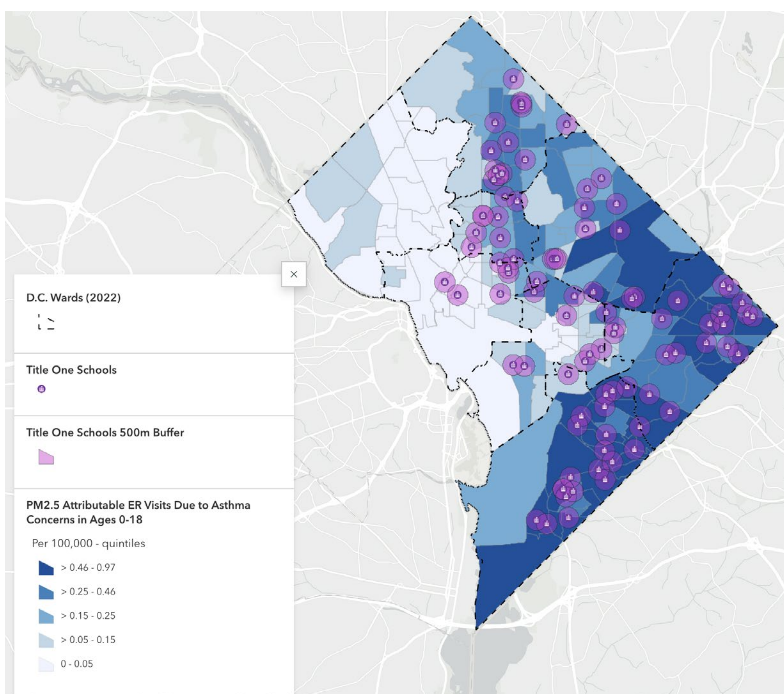


Figure 5. Title 1 School Distribution and $PM_{2.5}$ Attributable ER Visits Due to Asthma

Step 4. Explore Interventions

In this step, the goal is to translate data insights on pollution exposure, health outcomes, and community conditions into targeted actions. For teams with established plans—such as expanding air quality sensors, improving traffic management, or implementing greening initiatives—data helps prioritize areas with the greatest need. For example, EPA's AQS data can guide the placement of air quality sensors in underserved areas with high exposure, while USDOT traffic data can target emission reduction efforts in zones most affected by pollution.

For those weighing intervention options, the data can highlight gaps and offer insights for new strategies. Communities with both high exposure and poor health outcomes may benefit from additional green spaces, public health initiatives, or stricter traffic regulations. Visualizing different options can help reveal gaps, and thus strategic opportunities for investment.

Seeing it in Action: Mapping D.C.'s Existing Sensor Network

The D.C. Department of Environment and Energy (DOEE) intends to expand their sensor network, so we mapped the locations of AQS $PM_{2.5}$ and PurpleAir monitors to assess current coverage. Even before a formal analysis, we can spot potential gaps in Figure 6 in the south and southeastern areas, where we previously identified high-emission roads, elevated asthma prevalence, and high percentages of low-income populations and people of color.

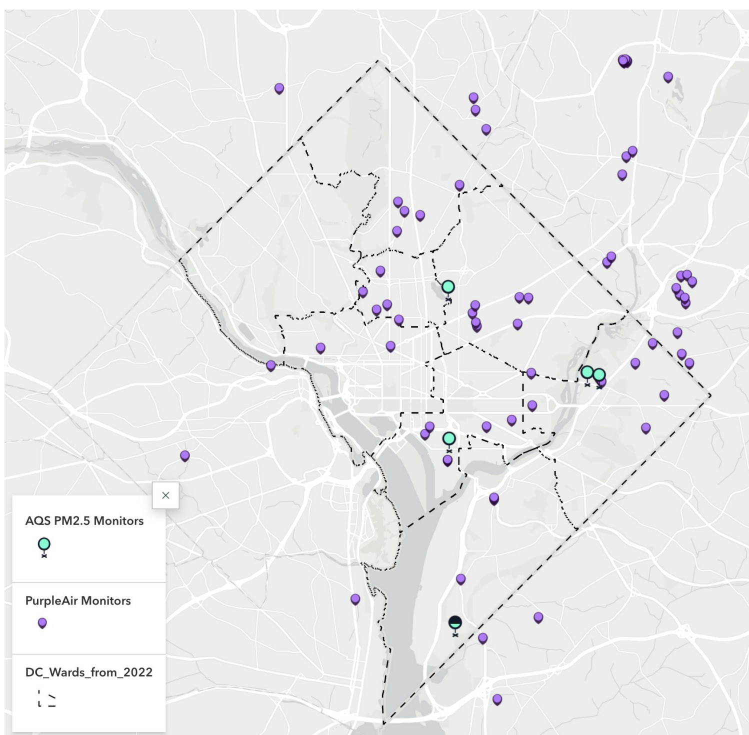


Figure 6. Existing Air Quality Monitor Networks

To formally integrate insights from the exposure, outcomes, and community conditions data, we proposed criteria to prioritize sites for new air monitors, identifying ten "high-priority" census tracts. These criteria were intended for city decision-makers to modify and formalize based on their priorities and context:

- More than one Title 1 school in the census tract.
- Proximity to one or more road segments with $PM_{2.5}$ emissions above average (>0.2 g/m/day).
- $PM_{2.5}$ Attributable ER Visits Due to Asthma Concerns in Ages 0-18 above average (>0.2 per 100,000) in a 1-mile buffer around Title 1 schools.
- Over 60% POC population in the census tract.

Figure 7 highlights the ten high-priority tracts along with the associated Title 1 schools for potential sensor placement. The map is overlaid with $PM_{2.5}$-attributable ER visits for children and the percentage of people of color.

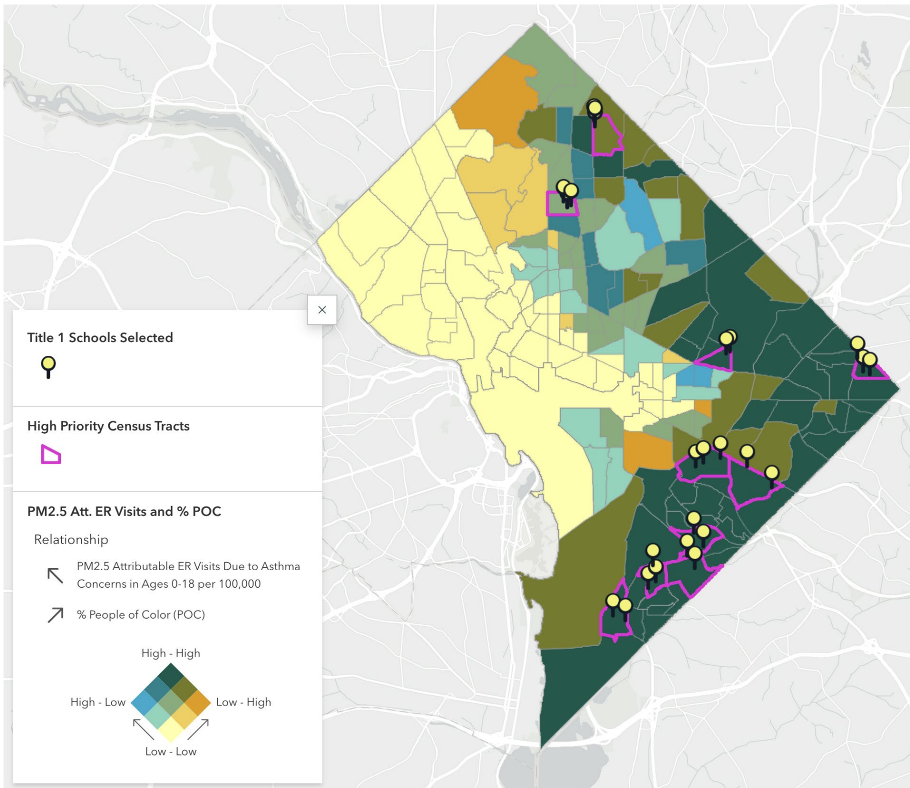


Figure 7. High-Priority Census Tracts for New Sensor Placement

An interactive map at the end of the Storymap allows users to toggle all possible data layers for an in-depth exploration of potential intersections.[xxx]

IV. Applying the Framework: Urban Heat Mitigation

This section applies the framework to urban heat mitigation. There are numerous data platforms and mapping tools readily available that city teams can use as a starting point and then supplemented with hyper localized data. The National Integrated Heat Health Information

System (NIHHIS) offers a comprehensive starting point of data, models, and tools developed to assess heat impacts on Heat.gov.[xxxi] Two complementary resources are the Climate Mapping for Resilience and Adaptation (CMRA)[xxxii] for identifying vulnerable areas and assessing future heat risks, and the U.S. Climate Resilience Toolkit,[xxxiii] which provides resources and case studies to help cities build resilience. This section explains how to navigate these resources, understand the relevant metrics, and where local data is needed to supplement them.

Step 1. Map Exposure

First, decide how to define "heat burden" in your city and then set appropriate thresholds for action. There are multiple commonly used metrics that each reveal different information. For example, some are better suited for large-scale resilience planning, others for specific interventions like cool roof installations. Here are the commonly used metrics with considerations on how and when to use them:

- **Air Temperature**: This is the most direct measure of heat exposure, indicating the conditions that people experience on the ground at different times of the day. This data, provided by NOAA’s National Weather Service, helps identify peak heat times as well as mid-day and nighttime temperatures.
- **Surface Temperature**: Mapped via NASA’s Landsat Program, surface temperature is crucial for understanding the urban heat island (UHI) effect and can provide insights on how infrastructure retains heat.
- **Heat Index**: This combines air temperature and humidity to estimate how hot it actually feels. NOAA’s Climate Data Online (CDO) provides real-time and historical data on heat index, helping cities assess heat stress and its health impacts, though it is challenging to measure at a localized scale.
- **Cooling Degree Days (CDD)**: CDD estimates the energy demand for cooling buildings, useful for assessing the economic impacts of heat. CDO offers seasonal and annual CDD data for energy planning.
- **Heatwave Frequency and Duration**: Tracking the length and frequency of heatwaves helps forecast health risks, particularly for vulnerable populations. CDO data helps cities prepare and proactively design health responses.

Next, it is important to set thresholds that align with the local context and priorities. Extreme heat is defined as prolonged periods of excessively hot weather above the regional average for that time of year, making context key.[xxxiv] Cities that face acute heat spikes, for example, may choose to focus on high-threshold events for emergency responses while cities that face frequent and sustained high heat days may select lower thresholds to address chronic impacts like school attendance. Other important factors include the region's healthcare capacity, overall population vulnerability and pre-existing conditions, and infrastructure resilience.

Step 2. Map Outcomes

Heat has a range of well-documented health impacts, including death, heat-related illnesses, respiratory and cardiovascular complications, and preterm births.[xxxv] To determine which outcomes to prioritize, it's important to consider your city's population vulnerabilities (i.e. prevalence of pre-existing conditions and proportion of elderly residents). Accessing health data can be a challenge, but there are different ways cities have successfully done so. Cities often use the following key metrics that capture heat-related health outcomes:

- **Heat-Related ER Visits**: ER data, typically available at the zip code level, tracks acute health impacts during heatwaves. This data helps identify neighborhoods in crisis and prioritize emergency responses, such as opening cooling centers. CDC PLACES can supplement this with localized health data to pinpoint at-risk areas.
- **Heat-Related Hospitalizations**: Hospitalization data provides insights into more severe or prolonged heat impacts, especially among vulnerable populations like the elderly. Access to this data often requires collaboration with health departments and healthcare systems, and is essential for preparing healthcare infrastructure. The CDC's National Vital Statistics System (NVSS) offers valuable data for assessing long-term health impacts.
- **Heat-Related Mortality**: Mortality data highlights the most severe outcomes of heat exposure, though it can be underreported and therefore involves only a small number of deaths, providing a limited sample size. NVSS helps cities track heat-related deaths, allowing them to allocate resources to areas with the highest risk of fatalities.
- **Chronic Conditions Aggravated by Heat**: Heat exacerbates conditions like cardiovascular and respiratory diseases. CDC PLACES provides neighborhood-level data on these chronic conditions, enabling cities to identify vulnerable populations and target interventions appropriately.

Miami-Dade County has published an impressive set of maps that capture heat-related hospitalizations and ER visits, excess deaths from high-heat days, and health vulnerability indices based on population risk.[xxxvi] For cities without localized health data, the CDC/ASTR Heat and Health Index (HHI)[xxxvii] is a valuable alternative, ranking ZIP codes based on a combination of temperature, health conditions, and sociodemographic factors to identify high-risk areas. Tools like Climate Explorer can be used alongside these metrics to project future heat risks and plan interventions accordingly.

Step 3. Map Community Conditions

The CDC's Social Vulnerability Index (SVI) is widely used to map vulnerable communities based on factors like income and housing quality. HUD data on housing infrastructure helps identify neighborhoods that lack cooling options, while the American Community Survey (ACS) provides demographic data on age and health conditions. Key groups to consider include:

- **High-Risk Groups**: This includes the elderly, pregnant people, young children, and those with pre-existing health conditions like heart disease, respiratory issues, and diabetes. Data from the U.S. Census Bureau and ACS can help cities identify these vulnerable populations by age, health status, and family composition.
- **High-Exposure Groups**: Outdoor workers (e.g., in construction and agriculture), the unhoused, and incarcerated individuals face greater heat risks due to prolonged exposure. Data on outdoor workers can be sourced from the ACS, while local housing and social services agencies provide information on the unhoused. State and local correctional departments can supply data on prison populations.
- **Residents of Under-Resourced, Historically Marginalized Communities**: Low-income Black and Brown communities, often in historically redlined areas, are disproportionately impacted by extreme heat due to fewer resources, less green space, and more heat-absorbing infrastructure. The CDC's SVI helps identify these communities, while HUD data and local housing authorities offer insights into housing quality and cooling access. Data on green space and infrastructure can be obtained through city planning departments.

Step 4. Explore Interventions

Building upon the previous steps, this one overlays current infrastructure and resources, allowing cities to identify where interventions will have the most impact. NIHHIS Heat.gov and the U.S. Climate Resilience Toolkit offer strategies and case studies, with common examples including:

- **Cooling Centers**: Cooling spaces provide immediate relief during heat waves, especially for those without access to air conditioning.[xxxviii] Cities can use local government and emergency management data to map existing cooling centers and identify gaps. NIHHIS Heat.gov also provides recommendations for optimizing placement in vulnerable areas.[xxxix] The Oklahoma City Office of Sustainability conducted a robust spatial analysis of urban heat health, which looked at at-risk populations, demographic data, and heat hotspots to inform how and where to place interventions, including cooling centers.[xl]
- **Urban Greening**: NASA's Landsat Program data is critical for mapping urban heat islands and identifying neighborhoods that would benefit from green infrastructure. City planning departments can then use this data to expand green spaces in the areas most affected by extreme heat.[xli] The city of Tucson, for example, created an interactive dashboard that utilizes a Tree Equity Score to identify neighborhoods in greatest need based on income, employment, race, age, and UHI severity.[xlii,xliii]
- **Reflective and Cool Roofing Materials**: Implementing reflective or cool roofing materials helps reduce heat absorption and lower indoor temperatures. Cities can use data from building departments to identify areas in need of upgrades.
- **Shade Structures and Heat-Resilient Infrastructure**: Installing shade structures in public spaces, such as bus stops and playgrounds, and developing heat-resilient infrastructure are critical for protecting residents from direct sunlight.[xliv] Municipal public works departments and urban planners can provide data on existing shade structures and potential sites for new installations. Mapping and modeling these interventions alongside vulnerable population data ensures that high-risk areas are prioritized.
- **Energy Assistance Programs**: Energy assistance programs are vital for ensuring that low-income households have access to air conditioning during heatwaves.[xlv] Local social service agencies and energy providers typically have data on program participation and, when mapped against income and housing quality layers from the ACS and HUD, helps target resources to those who need them most.

Conclusion

The framework in this guide empowers cities to use spatial analytics to strategically address environmental health issues, prioritizing resources where they are needed most. Case studies from Washington, D.C., and other cities show how GIS can embed equity and health into decision-making, helping cities tackle air pollution, urban heat, and other environmental risks. This flexible framework offers a clear roadmap for designing and implementing targeted interventions based on local data.

GIS also plays a crucial role in aligning city departments, securing funding, and communicating environmental challenges to the public. By integrating data-backed insights and community input, cities can create more effective policies and adapt them over time. However, this is an ongoing process that requires continual evaluation and refinement as new data emerges.

By embracing GIS and spatial analytics, cities can build healthier, more resilient communities, reduce disparities, and improve public health. Now is the time to act and apply these tools for a more equitable future.

Appendix

Analytical Tools

Cities have access to numerous free, web-based tools, as well as resources available through platforms like Esri. Esri's ArcGIS platform,[xlvi] including tools like Social Equity Analysis[xlvii] and Community Health Assessment,[xlviii] provides powerful GIS capabilities tailored for urban planning and public health. Many cities also benefit from Esri's Living Atlas,[xlix] a vast collection of global data layers that can enhance local datasets for deeper analysis of environmental and health risks. With most cities already holding Esri contracts, these tools are easily deployable, and for those with limited technical capacity, pre-configured templates make them accessible.

The table below highlights a combination of freely available tools and those accessible through Esri and similar GIS services, organized by their relevance to exposure, outcomes, community conditions, and interventions.

Tool	Topic Relevance	Use Cases & Considerations
CDC Heat & Health Tracker[l]	Heat	Real-time monitoring of potential heat stress and heat-related illnesses, tracking temperature trends. May need to combine with local datasets for complete insights.
US Climate Resilience Toolkit, Climate Explorer[li]	Heat	Provides climate data projections, particularly for heat-related risks, useful for long-term resilience planning. Offers climate projections but may lack detail for neighborhood-level interventions.
EJScreen[lii]	Air Pollution, Heat	Integrates air pollution data with demographic data to identify vulnerable populations. Updated annually; detailed analysis requires additional GIS work for hyperlocal targeting.
CDC Social Vulnerability Index (SVI)[liii]	Air Pollution, Heat	Identifies socially vulnerable communities exposed to air pollution or heat hazards. Social factors must be combined with environmental data for a complete risk assessment.
CDC National Environmental Public Health Tracking Network[liv]	Air Pollution, Heat	Combines air quality and heat-related illness data to help cities monitor environmental health impacts. Requires environmental health knowledge to navigate and utilize the broad range of indicators.
EnviroAtlas (US EPA)[lv]	Air Pollution, Heat	Integrates air quality data with other environmental and health indicators, helping cities assess pollution impacts. Extensive data requires technical expertise to extract relevant information for air pollution and heat risks.
US Climate Vulnerability Index[lvi]	Air Pollution	Provides assessments of regional vulnerability to climate-related risks, including air pollution and heat. Useful for identifying areas most susceptible to environmental health risks. It requires supplemental local data for detailed interventions.
AirNow (US EPA)[lvii]	Air Pollution	Tracks real-time air quality data for pollutants like ozone, $PM_{2.5}$, and NO2; useful for issuing health advisories. Broad regional data; hyperlocal air quality sensor networks may be needed for more precise data.

---

[i] Stephen Goldsmith and Khahlil Louisy, *A Framework for Reducing Place-Based Inequity* (Data-Smart City Solutions, Harvard University, 2023). https://datasmart.hks.harvard.edu/framework-reducing-place-based-inequity.

[ii] City of Hopkins, *Understanding Place-Based Inequity Using GIS*, ArcGIS StoryMaps, accessed July 25, 2024, https://storymaps.arcgis.com/stories/8279b5ccc3e24b8199581d8cd0eaac85#ref-n-hQrq7Z.

[iii] Multnomah County, *2024 Heat Vulnerability Index*, ArcGIS, accessed July 25, 2024, https://experience.arcgis.com/experience/0af8ec76c2024e6980bf83771a165a0a.

[iv] Karen Sullivan, *Cities Save Lives by Mapping Communities Most at Risk from Extreme Heat*, ArcUser, ArcUser Winter 2024, https://www.esri.com/about/newsroom/arcuser/extreme-heat/.

[v] Environmental Defense Fund. *The Warehouse Boom: Impacts of Warehouse Growth on Air Quality and Public Health in New York City*. January 18, 2023. https://globalcleanair.org/wp-content/blogs.dir/95/files//EDF-NY-Warehouse-Boom-Report-1-18-23.pdf.

[vi] Maria Torres-Springer, May 22, 2024, "Letter to Speaker Adrienne Adams," (New York City, 2024), https://earthjustice.org/wp-content/uploads/2024/05/20240522_letter_to_speakeradams_recoyeo_final.pdf.

[vii] United States Environmental Protection Agency, *Climate Pollution Reduction Grants*, last updated on September 9, 2024, https://www.epa.gov/inflation-reduction-act/climate-pollution-reduction-grants.

[viii] United States Environmental Protection Agency, *Air Quality Information: Making Sense of Air Pollution Data to Inform Decisions in Underserved Communities Overburdened by Air Pollution Exposures Funding Opportunity*, last updated May 2, 2024, https://www.epa.gov/research-grants/air-quality-information-making-sense-air-pollution-data-inform-decisions.

[ix] *ResilientMass Plan: 2023 MA State Hazard Mitigation and Climate Adaptation Plan*, (Massachusetts, 2023), https://www.mass.gov/doc/resilientmass-plan-2023/download.

[x] Muen Zhang, Alex Adame, *Using Spatial Data to Build an Equitable Sensor Network*, last updated October 10, 2024, https://arcg.is/0rWqyT0.

[xi] United States Environmental Protection Agency, *Criteria Air Pollutants*, last updated on July 30, 2024, https://www.epa.gov/criteria-air-pollutants.

[xii] United States Environmental Protection Agency, *Hazardous Air Pollutants*, last updated on September 4, 2024, https://www.epa.gov/haps.

[xiii] Environmental Defense Fund, *Clean Air and Better Health for All - Developing Data Driven Decisions in Cities*. Distributed at the CDHI Creating Equitable Air Quality Solutions Workshop, September 20, 2024.

[xiv] United States Environmental Protection Agency, *Air Quality System (AQS)*, last updated on September 17, 2024, https://www.epa.gov/aqs.

[xv] NASA Health and Air Quality Applied Sciences Team, *Satellite Data for Environmental Justice*, 2023, https://haqast.org/.

[xvi] Environmental Defense Fund, *Clean Air and Better Health for All - Developing Data Driven Decisions in Cities*. Distributed at the CDHI Creating Equitable Air Quality Solutions Workshop, September 20, 2024.

[xvii] Centers for Disease Control and Prevention, *PLACES: Local Data for Better Health*, last reviewed August 29, 2024, https://www.cdc.gov/places/index.html.

[xviii] Agency for Toxic Substances and Disease Registry, *CDC/ATSDR Social Vulnerability Index (CDC/ATSDR SVI)*, last reviewed June 14, 2024, https://www.atsdr.cdc.gov/placeandhealth/svi/index.html.

[xix] United States Environmental Protection Agency, *EJScreen: Environmental Justice Screening and Mapping Tool*, last updated September 9, 2024 https://www.epa.gov/ejscreen.

[xx] L.A. Controller Ron Galperin, *A Great Divide: L.A. Equity Index*, ArcGIS StoryMaps, accessed July 25, 2024, https://storymaps.arcgis.com/stories/ca477e68657643c9a2bad1fddfe24359.

[xxi] City of Tacoma, *Equity Index*, last updated July 2024, https://www.cityoftacoma.org/cms/One.aspx?portalId=169&pageId=175030.

[xxii] Council on Environmental Quality, *Climate and Economic Justice Screening Tool*, 2022, https://screeningtool.geoplatform.gov/en/#3/33.47/-97.5.
[xxiii] Environmental Defense Fund, *The U.S. Climate Vulnerability Index*, https://climatevulnerabilityindex.org/.
[xxiv] Note: EJScreen uses the term "minority" to refer to individuals who list their racial status as a race other than white alone and/or list their ethnicity as Hispanic or Latino.
[xxv] Industrial Economics, Incorporated, *Analysis of PM2.5-Related Health Burdens Under Current and Alternative NAAQS: updated final report, 9 µg/m3 supplement added March 21, 2023*, Global Clean Air.org, https://globalcleanair.org/wp-content/blogs.dir/95/files/2023/03/Updated-IEc-PM-NAAQS-Analysis-March-2023.pdf.
[xxvi] Gaige Hunter Kerr, et al., *Increasing Racial and Ethnic Disparities in Ambient Air Pollution-Attributable Morbidity and Mortality in the United States*, Environmental health perspectives vol. 132,3 (2024): 37002. doi:10.1289/EHP11900.
[xxvii] Maria D Castillo, et al., *Estimating Intra-Urban Inequities in PM2.5-Attributable Health Impacts: A Case Study for Washington, DC*, GeoHealth vol. 5,11 e2021GH000431. 1 Nov. 2021, doi:10.1029/2021GH000431.
[xxviii] Sathya Swarup Aithal, et al., *Air quality and respiratory health in children*, Breathe (Sheffield, England) vol. 19,2 (2023): 230040. doi:10.1183/20734735.0040-2023.
[xxix] Ruben Garnica-Monroy, et al., *Spatial Analysis of Exposure to Traffic-Related Air Pollution in Mexico: Implications for Urban Planning to Improve Public Health*, Applied Spatial Analysis and Policy, 15, 647–665 (2022). https://doi.org/10.1007/s12061-021-09415-1.
[xxx] Muen Zhang, Alex Adame, *Using Spatial Data to Build an Equitable Sensor Network*, last updated September 11, 2024, https://arcg.is/0rWqyT0.
[xxxi] U.S. National Integrated Heat Health Information System. "Tools & Information." Heat.gov. Accessed September 2, 2024. https://www.heat.gov/pages/tools-information.
[xxxii] U.S. Climate Resilience Toolkit. Climate Resilience Toolkit. Accessed October 7, 2024. https://resilience.climate.gov/.
[xxxiii] U.S. Climate Resilience Toolkit. *U.S. Climate Resilience Toolkit*. Accessed October 7, 2024. https://toolkit.climate.gov/.
[xxxiv] Federal Emergency Management Agency, *Extreme Heat*, https://community.fema.gov/ProtectiveActions/s/article/Extreme-Heat-What#.
[xxxv] U.S. Environmental Protection Agency. Heat Island Impacts. Accessed October 7, 2024. https://www.epa.gov/heatislands/heat-island-impacts.
[xxxvi] Esri. Environmental Justice Index: Ranking Cumulative Health Impacts by Census Tract. Accessed October 7, 2024. https://storymaps.arcgis.com/stories/6f1e91cf8a8e4d5d9bd67525575c042e.
[xxxvii] Centers for Disease Control and Prevention. Heat and Health Tracker. Accessed October 7, 2024. https://ephtracking.cdc.gov/Applications/heatTracker/.
[xxxviii] Stephen Goldsmith, Betsy Gardner, *Mapping a Path to Resilience in Los Angeles*, December 7, 2023, https://datasmart.hks.harvard.edu/mapping-path-resilience-los-angeles
[xxxix] Stasia Widerynski, et al. *Use of cooling centers to prevent heat-related illness: summary of evidence and strategies for implementation*, 2017, doi:10.13140/RG.2.2.32267.59688.
[xl] City of Oklahoma City. Urban Heat and Health OKC. Accessed October 5, 2024. https://okc-urban-heat-health-okc.hub.arcgis.com/apps/c53972fdc60949a3bfe30ea20d0b6d7f/explore.
[xli] Stephen Goldsmith, *Fighting Climate Change with Data-Driven Urban Forestry*, December 13, 2023, https://datasmart.hks.harvard.edu/fighting-climate-change-data-driven-urban-forestry.
[xlii] Esri. Mapping for Resilience: Climate and Economic Justice Screening Tool. Accessed October 7, 2024. https://experience.arcgis.com/experience/ef686020e5bb483f9840aedb6dc43bbc/.
[xliii] Harvard Kennedy School. Building Extreme Heat Resilience in Tucson with a Million Trees. Data-Smart City Solutions. Accessed October 6, 2024. https://datasmart.hks.harvard.edu/building-extreme-heat-resilience-tucson-million-trees.
[xliv] Kelly Turner, interview with Stephen Goldsmith, The Data-Smart City Pod, podcast audio, September 4, 2024, https://datasmart.hks.harvard.edu/how-urban-planning-and-shade-design-can-combat-extreme-heat.

[xlv] Lindsey Burghardt, interview with Stephen Goldsmith, The Data-Smart City Pod, podcast audio, August 14, 2024, https://datasmart.hks.harvard.edu/invisible-impact-heat-and-childrens-health.
[xlvi] Esri, *ArcGIS*, accessed October 7, 2024. https://www.esri.com/en-us/arcgis/products/index.
[xlvii] Esri, *Social Equity Analysis*, accessed October 7, 2024. https://www.esri.com/en-us/arcgis/solutions/social-equity-analysis.
[xlviii] Esri, *Community Health Assessment*, accessed October 7, 2024. https://www.esri.com/en-us/arcgis/solutions/community-health-assessment.
[xlix] Esri, *Living Atlas of the World*, accessed October 7, 2024. https://livingatlas.arcgis.com/en/.
[l] Centers for Disease Control and Prevention, *Heat & Health Tracker*, accessed October 7, 2024. https://www.cdc.gov/heat-health-tracker.
[li] United States Global Change Research Program, *US Climate Resilience Toolkit: Climate Explorer,* accessed October 7, 2024. https://toolkit.climate.gov/tools/climate-explorer.
[lii] U.S. Environmental Protection Agency, *EJScreen: Environmental Justice Screening and Mapping Tool*, accessed October 7, 2024. https://www.epa.gov/ejscreen.
[liii] Centers for Disease Control and Prevention, *Social Vulnerability Index*, accessed October 7, 2024. https://www.atsdr.cdc.gov/placeandhealth/svi/index.html.
[liv] Centers for Disease Control and Prevention, *Environmental Public Health Tracking Network: Data Explorer*, accessed October 7, 2024. https://ephtracking.cdc.gov/DataExplorer/.
[lv] U.S. Environmental Protection Agency, *EnviroAtlas*, accessed October 7, 2024. https://www.epa.gov/enviroatlas.
[lvi] Texas A&M University, *Climate Vulnerability Index*, accessed October 7, 2024. https://climatevulnerabilityindex.org/.
[lvii] U.S. Environmental Protection Agency, *AirNow: Air Quality Index*, accessed October 7, 2024. https://www.airnow.gov.